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**Mower**

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(54) **METHODS, APPARATUS, AND SYSTEMS FOR MULTIPLE STIMULATION FROM A SINGLE STIMULATOR**

(75) Inventor: **Morton M Mower**, Baltimore, MD (US)

(73) Assignee: **Mirowski Family Ventures, L.L.C.**, Washington, DC (US)

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(52) **U.S. Cl.** ................ **607/148**; 607/9; 607/11; 607/34; 607/66

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See application file for complete search history.

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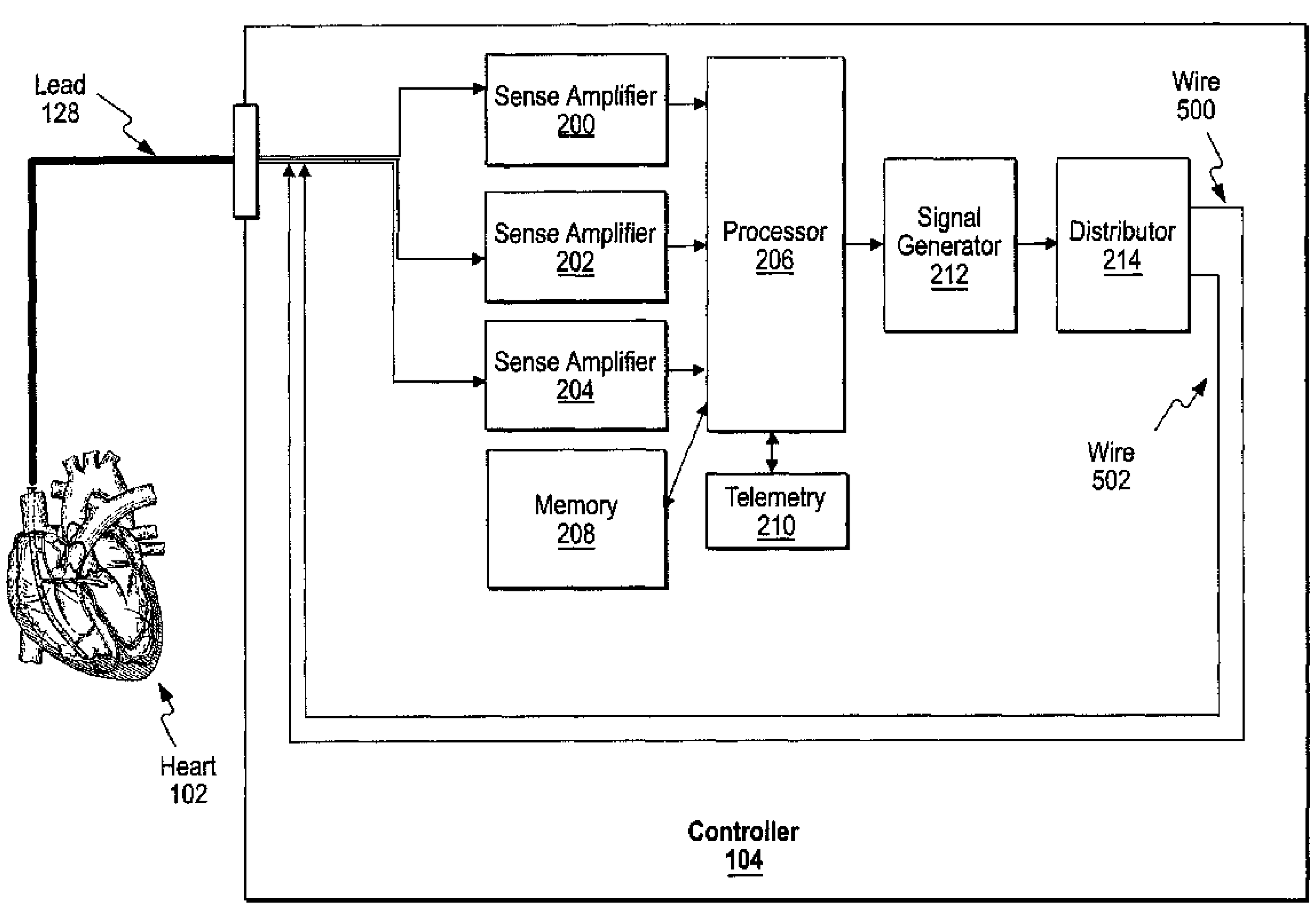
*Primary Examiner* — Carl H Layno
*Assistant Examiner* — Natasha Patel
(74) *Attorney, Agent, or Firm* — Oblon, Spivak, McClelland, Maier & Neustadt, L.L.P.

(57) **ABSTRACT**

Methods, apparatus, and systems are provided to stimulate multiple sites in a heart. A controller senses electrical activity associated with sinus rhythm of the heart. A signal generator is configured to generate an electrical signal for stimulating the heart. Based on the electrical signal, a distributor circuit then distributes the stimulating signals, such as pacing pulses, to a heart. The distributor circuit may vary the delay time between stimulating signals, inhibit a stimulating signal, trigger application of a stimulating signal, or vary the characteristics, such as the pulse width and amplitude, of a stimulating signal.

**11 Claims, 9 Drawing Sheets**



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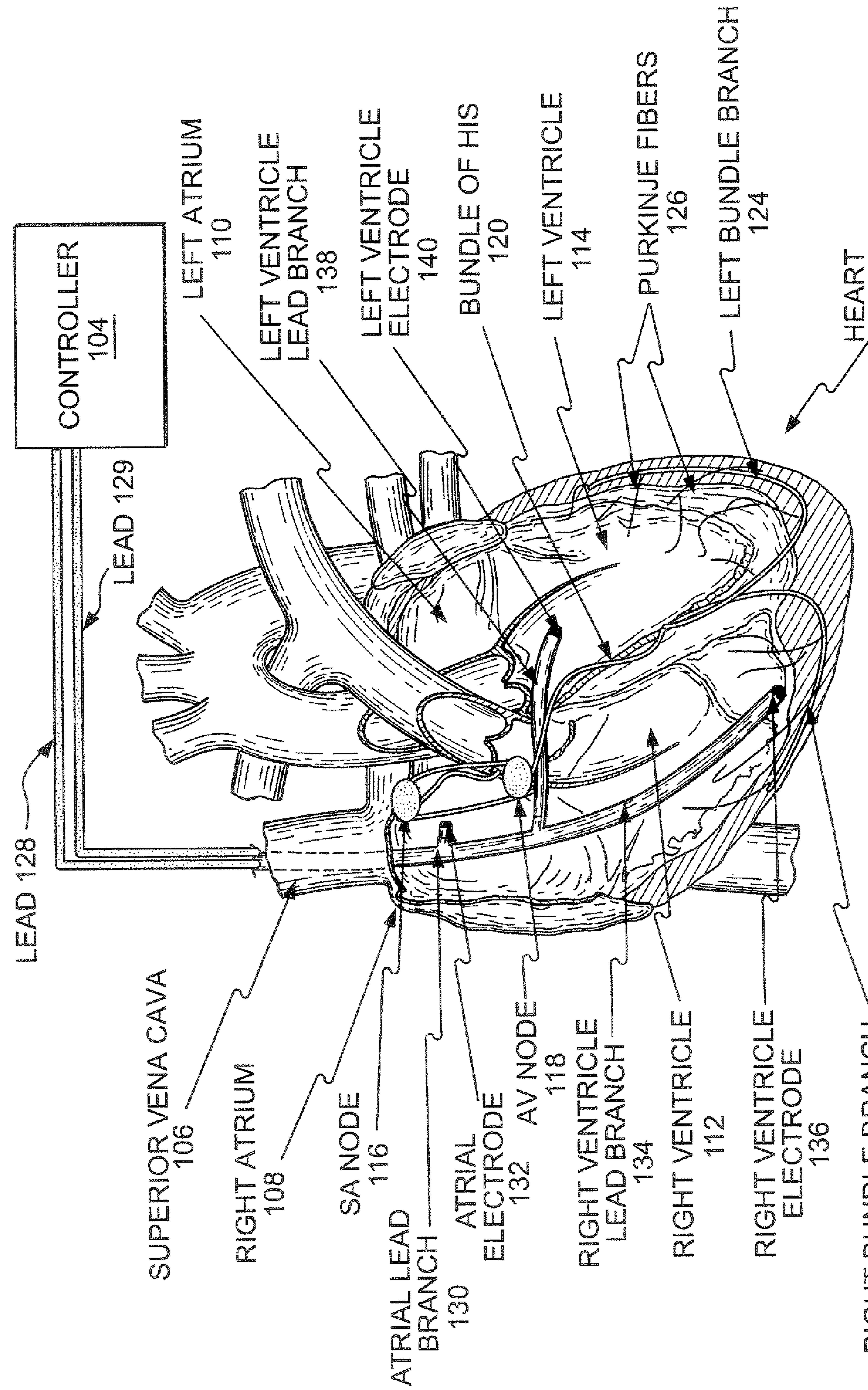
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LEAD 128
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AV NODE
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RIGHT VENTRICLE
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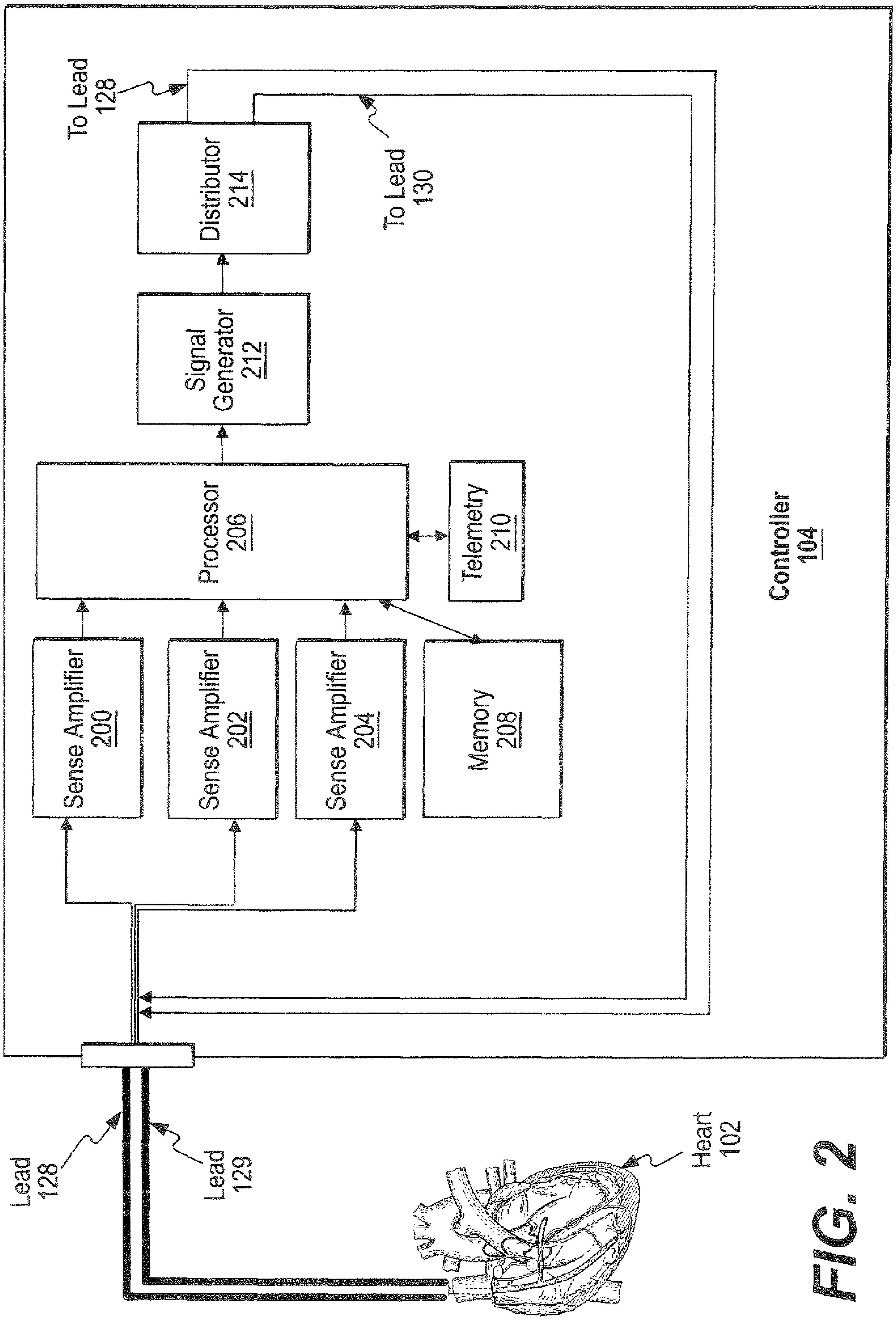
136
RIGHT BUNDLE BRANCH
122

*FIG. 1*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Sense Amplifier 204
Memory 208
Lead 128
Lead 129
Heart 102

FIG. 2

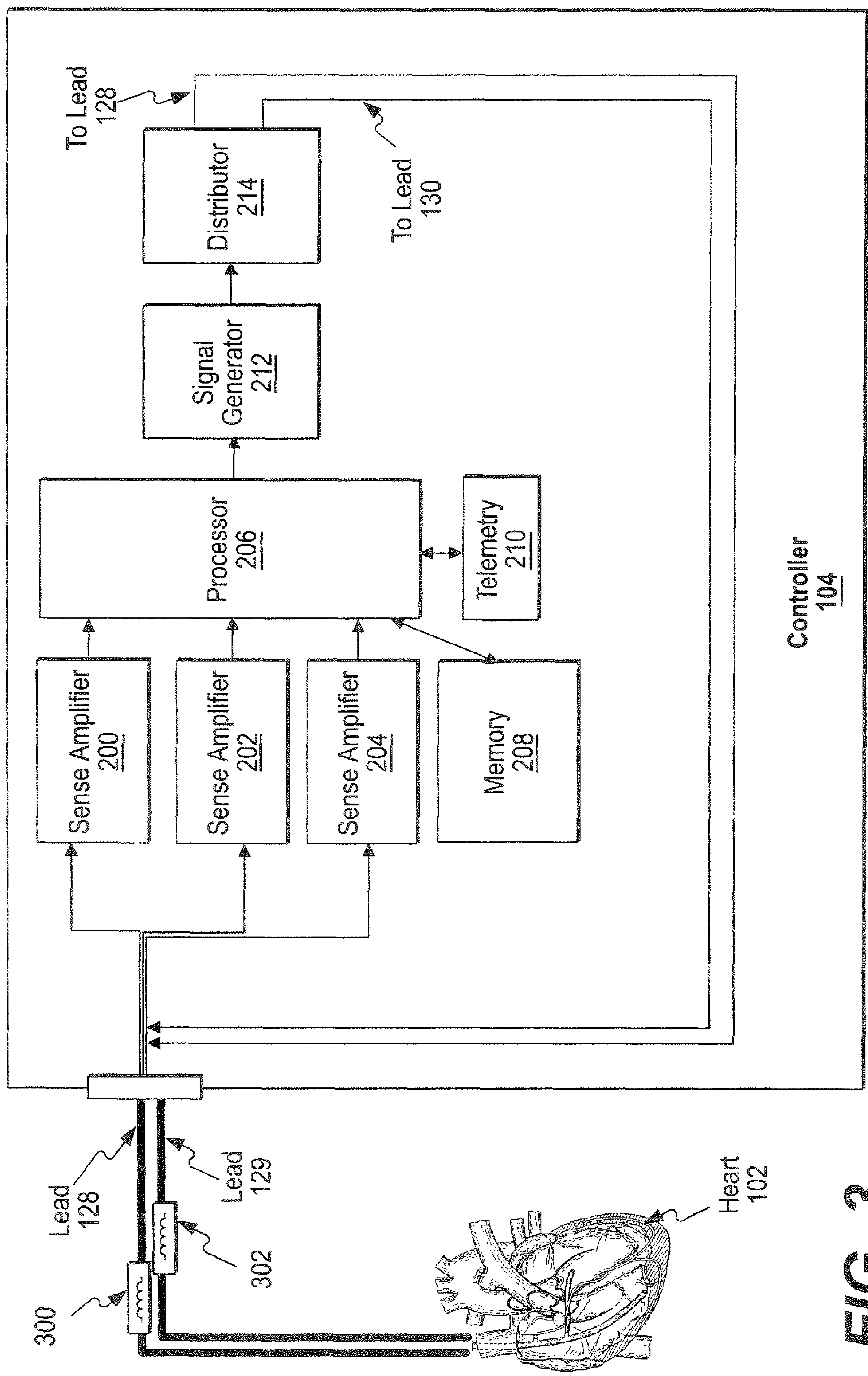

To Lead 128
Distributor 214
To Lead 130
Signal Generator 212
Processor 206
Telemetry 210
Controller 104
Sense Amplifier 200
Sense Amplifier 202
Sense Amplifier 204
Memory 208
Lead 128
Lead 129
300
302
Heart 102

FIG. 3

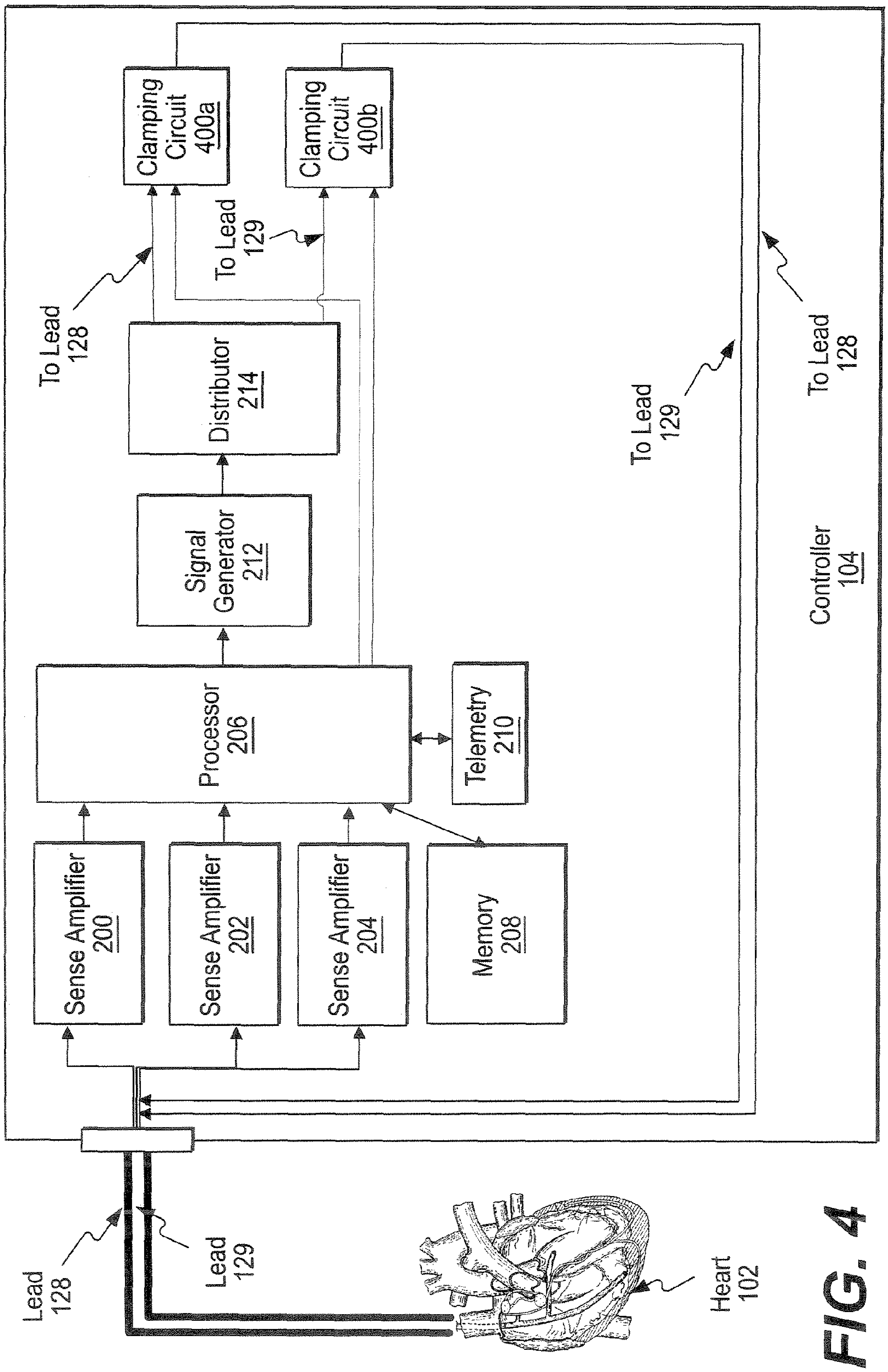

Clamping Circuit 400a
Clamping Circuit 400b
To Lead 128
To Lead 129
Distributor 214
Signal Generator 212
Processor 206
Telemetry 210
Sense Amplifier 200
Sense Amplifier 202
Sense Amplifier 204
Memory 208
To Lead 129
To Lead 128
Controller 104
Lead 128
Lead 129
Heart 102

FIG. 4

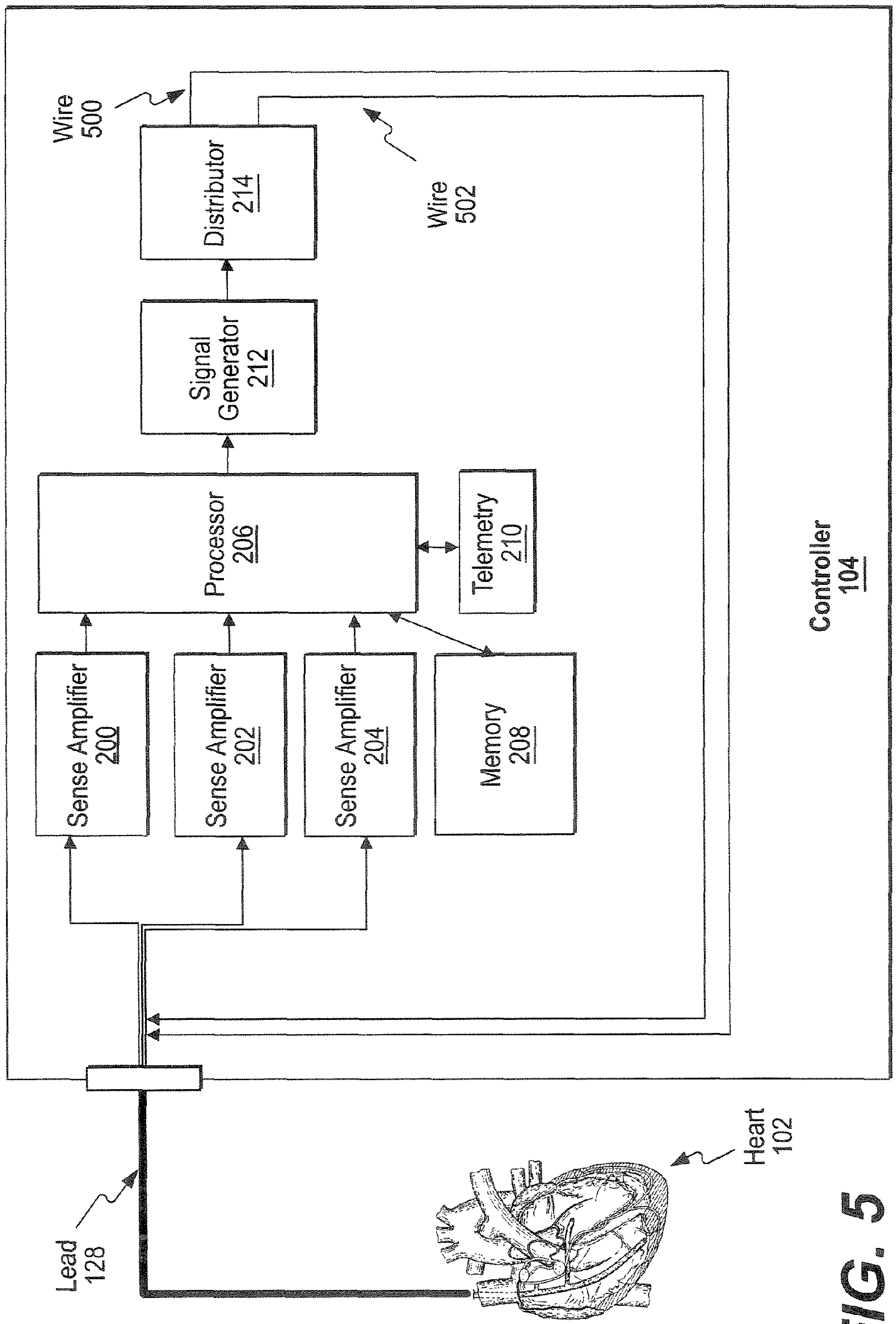

Wire 500
Wire 502
Distributor 214
Signal Generator 212
Processor 206
Telemetry 210
Sense Amplifier 200
Sense Amplifier 202
Sense Amplifier 204
Memory 208
Controller 104
Lead 128
Heart 102

FIG. 5

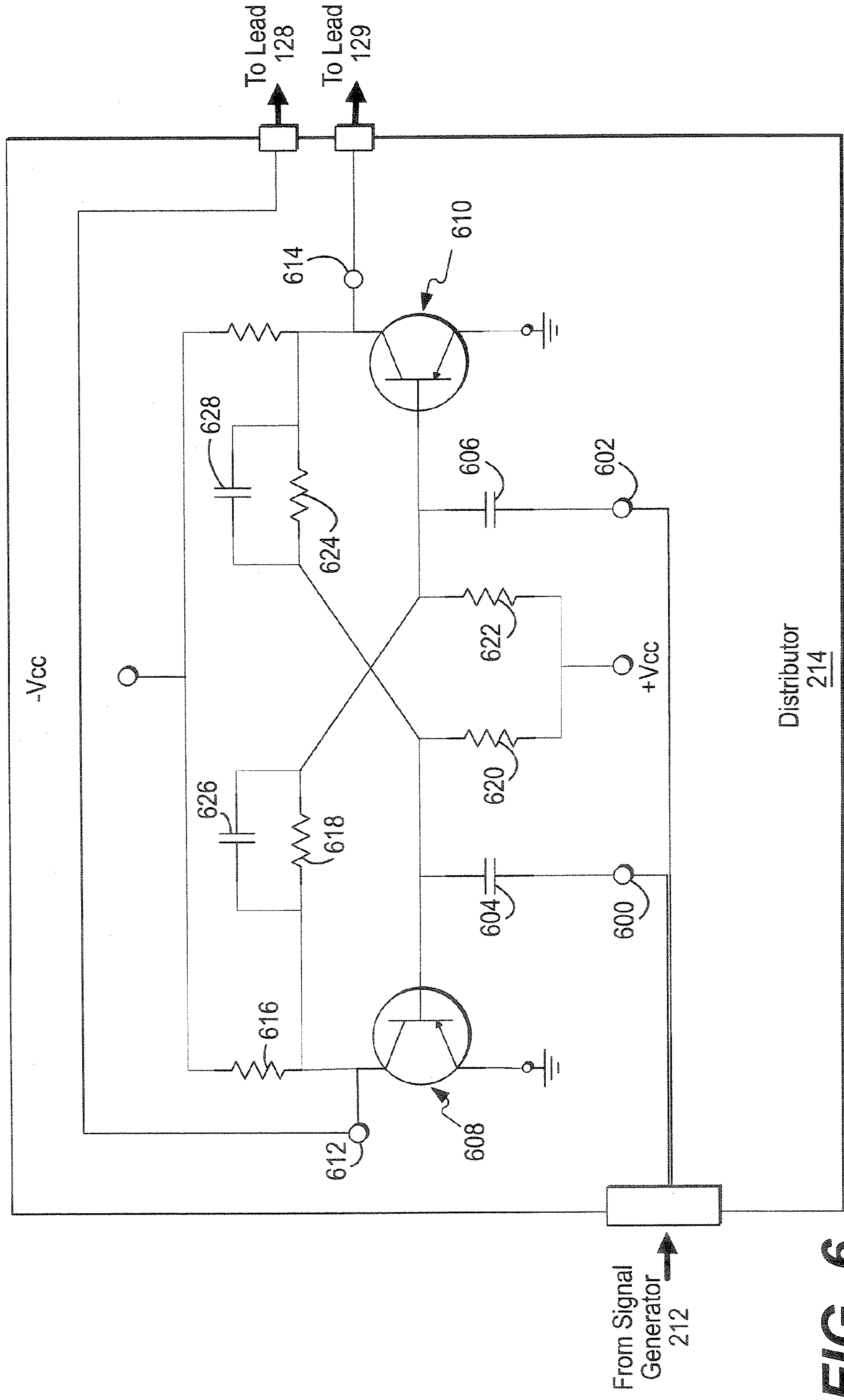

To Lead 128
To Lead 129
610
614
628
624
606
602
-Vcc
622
+Vcc
Distributor
214
626
618
620
604
600
616
612
608
From Signal Generator 212

FIG. 6

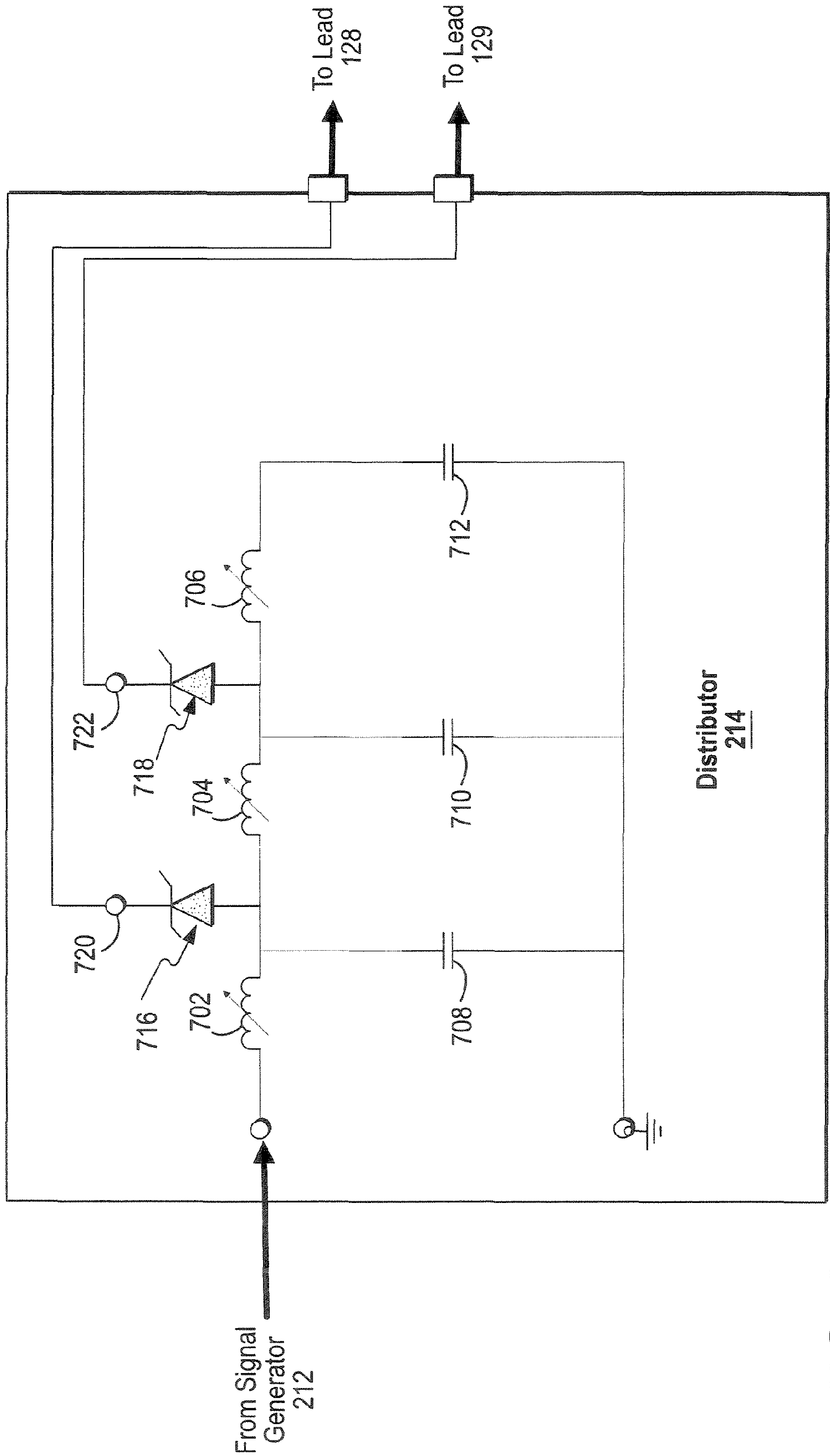

To Lead 128
To Lead 129
706
712
722
718
704
710
720
716
702
708
Distributor 214
From Signal Generator 212

FIG. 7

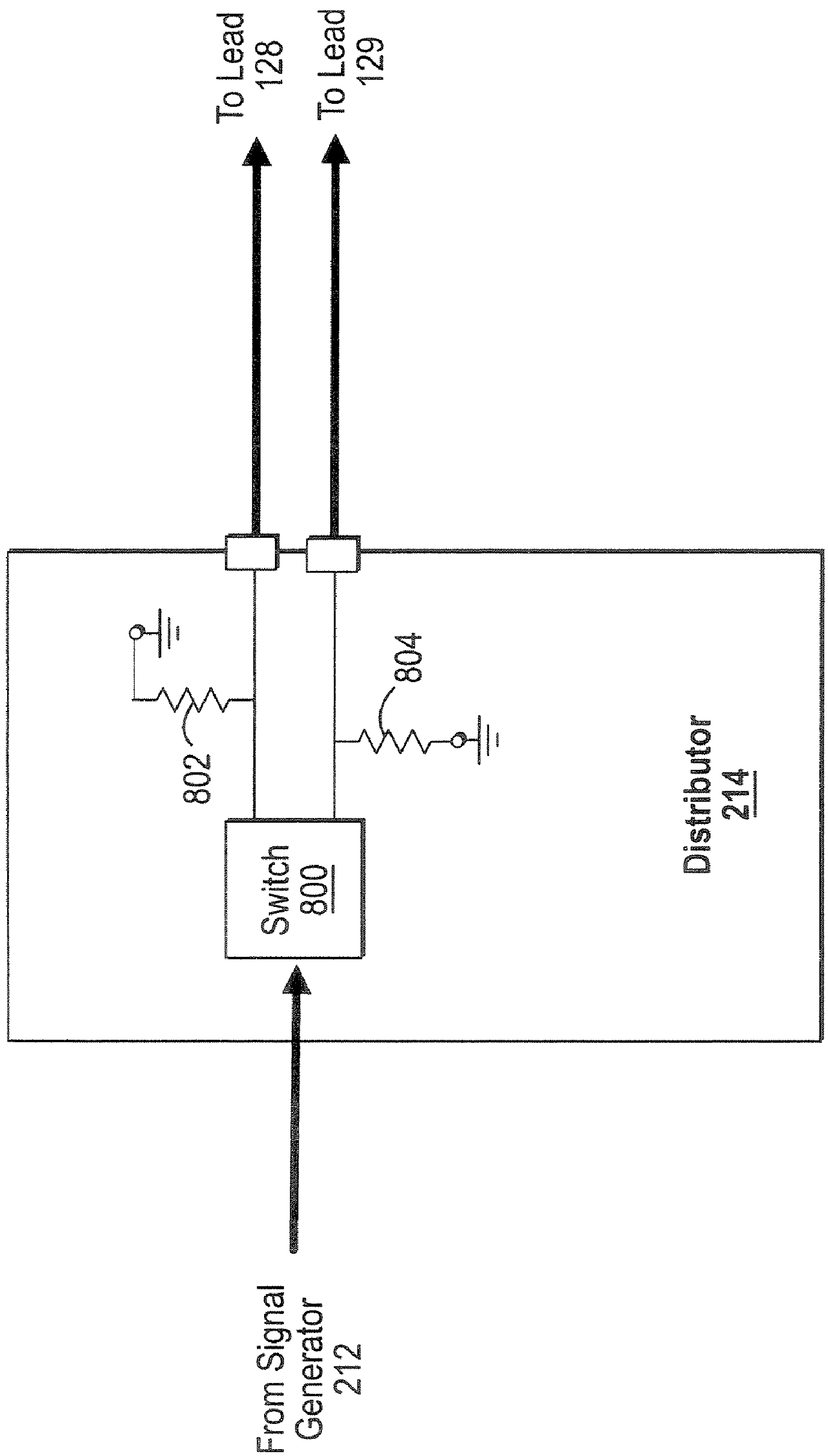
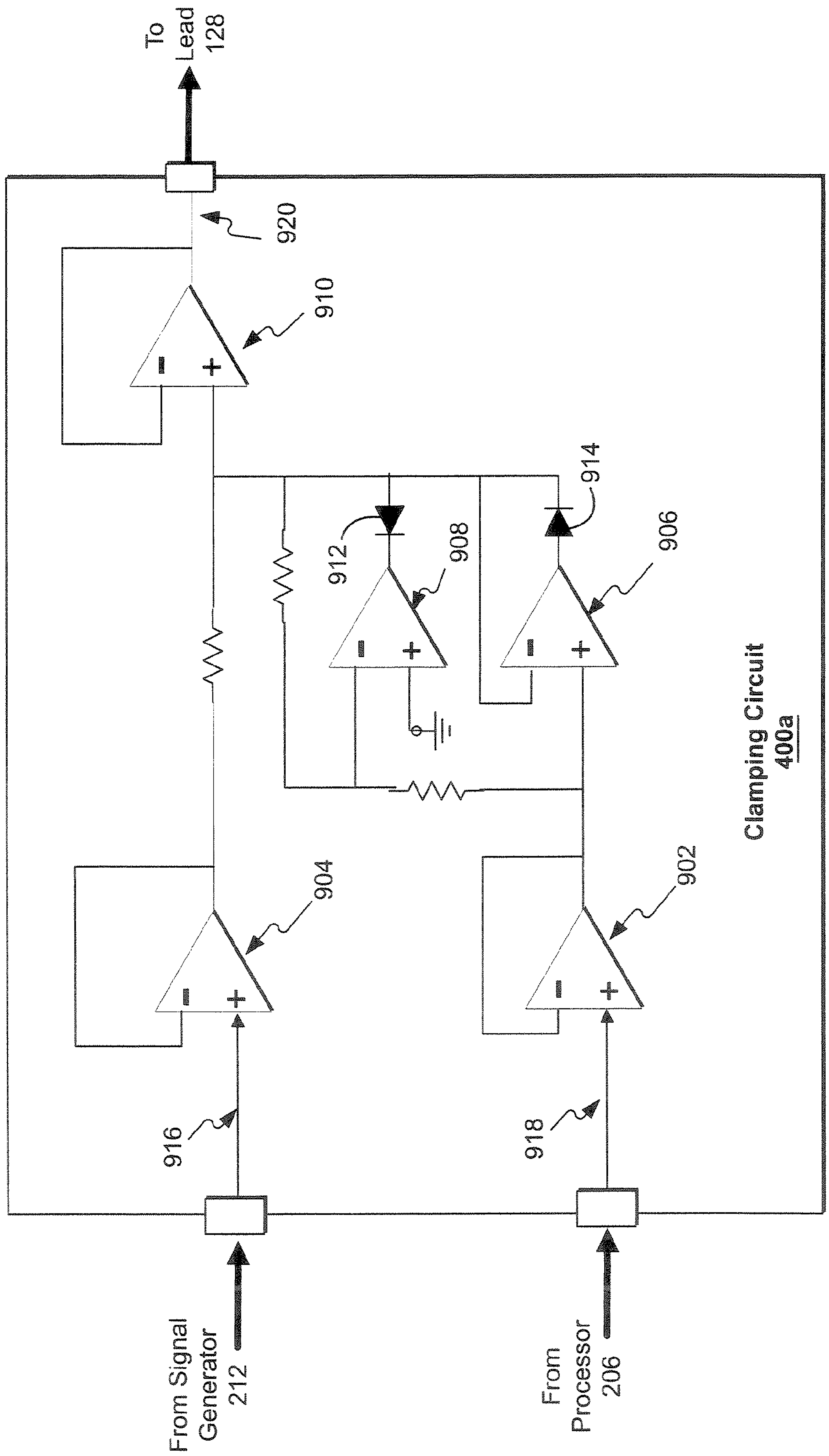

To Lead
128
To Lead
129
802
804
Switch
800
Distributor
214
From Signal
Generator
212

FIG. 8



To Lead 128
920
910
914
912
908
906
904
902
916
918
Clamping Circuit 400a
From Signal Generator 212
From Processor 206


FIG. 9

# METHODS, APPARATUS, AND SYSTEMS FOR MULTIPLE STIMULATION FROM A SINGLE STIMULATOR

The present application is a DIVISION of application Ser. No. 10/625,526, filed Jul, 24, 2003, now U.S. Pat. No. 7,231, 249.

## FIELD OF THE INVENTION

The present invention relates to cardiac stimulators, and in particular, to methods, apparatus, and systems for pacing multiple sites in a heart.

## BACKGROUND

During a normal heartbeat, the heart contracts in a coordinated fashion to pump blood. In particular, the heart contracts based on rhythmic electrical impulses, which are spread over the heart using specialized fibers. These rhythmic electrical pulses are initiated by the heart's natural pacemaker called the sinoatrial node ("SA node"). The SA node initiates electrical impulses to cause the right and left atrium to contract. As the atria contract, the electrical impulses from the SA node propagate to the atrial-ventricular node ("AV node"). After an inherent delay in the AV node, the AV node then transmits the electrical impulses, which eventually causes contraction in the right and left ventricles. The inherent delay of the AV node is known as the A-V delay and allows the atria to fully contract and fill the ventricles with blood. Blood from the ventricles then flows out of the heart and to the rest of the body. Therefore, the heart relies upon a rhythmic cycle of electrical impulses to pump blood efficiently.

A heart may suffer from one or more cardiac defects that interfere with the rhythmic cycle or conduction of electrical impulses. For example, one known heart condition is an AV nodal block. An AV nodal block inhibits transfer of impulses from the SA node to the AV node, and thus, inhibits or prevents contraction of the right and left ventricles. Other conditions, such as myocardial scarring and bundle branch block, may slow conduction of impulses, and thus, cause the heart to beat in an uncoordinated fashion.

In diseased hearts having conduction defects and in congestive heart failure (CHF), cardiac depolarizations that naturally occur in one upper or lower heart chamber are not conducted in a timely fashion either within the heart chamber or to the other upper or lower heart chamber. In such cases, the right and left heart chambers do not contract in optimum synchrony with one another, and cardiac output suffers.

Typically, an artificial pacemaker is installed to treat these and other various cardiac deficiencies For example, in the case of loss of A-V synchrony, a single chamber, demand pacemaker may sense impulses from the SA node and then supply stimulating electrical pulses to the ventricles to cause contraction in the right and left ventricles. In this manner, an artificial pacemaker may compensate for blocked or slowed conduction of electrical impulses from the atrium to the ventricles in the heart.

Dual chamber, demand pacemakers typically supply pacing pulses when required to one upper heart chamber and to one lower heart chamber, usually the right atrium and the right ventricle. In a dual chamber, demand pacemaker operating in DDD pacing mode, an atrial pacing pulse is delivered to the atrium if an atrial contraction is not sensed within an atrial escape interval (A-A interval) and a ventricular pacing



pulse is delivered to the ventricle if a ventricular contraction is not sensed within a ventricular escape interval (V-V interval).

Patients suffering from congestive heart failure and other conduction defects may require bi-ventricular and/or bi-atrial pacing. For example, in a dual chamber bi-atrial pacemaker, the right atrium may be paced at the expiration of an A-A escape interval, and the left atrium is synchronously paced or paced after a short delay. In a dual chamber bi-ventricular pacemaker, the right ventricle may be paced at the expiration of a V-V escape interval, and the left ventricle is synchronously paced or paced after a short delay time. In a single chamber pacemaker with bi-chamber pacing, a pacing pulse delivered at the end of an AV delay may trigger the simultaneous or slightly delayed delivery of the pacing pulse to the other heart chamber.

In order to provide stimulating electrical pulses, known artificial pacemakers may include multiple stimulators. Furthermore, an artificial pacemaker may include multiple stimulators that are triggered at different times to provide dual chamber and/or bi-chamber pacing. Unfortunately, providing and controlling multiple stimulators increases the number of components that may fail within an artificial pacemaker.

Accordingly, it would be desirable to provide methods, apparatus, and systems, which can avoid using multiple stimulators and overcome other deficiencies in the prior art.

## SUMMARY OF THE INVENTION

In accordance with an aspect of the present invention, a dual chamber cardiac pacemaker comprises a first electrode, a second electrode, a signal generator, a first lead, a second lead, and a distributor circuit. The first electrode electrically is coupled to an atrial chamber. The second electrode is electrically coupled to a ventricular chamber. The signal generator generates a sequential pair of electrical pacing pulses. The first lead is coupled to the signal generator and to the first electrode and the second lead is coupled to the signal generator and to the second electrode. The distributor circuit is connected between the first lead and the signal generator and between the second lead and the signal generator. The distributor circuit receives the pair of electrical pacing pulses, distributes a first pacing pulse from the pair at a first amplitude to the first lead and distributes a second pacing pulse from the pair at a second amplitude to the second lead after a delay period.

In accordance with another aspect of the present invention, a bi-chamber cardiac pacemaker comprises a first electrode, a second electrode, and a lead. The first electrode is electrically coupled to a left chamber and the second electrode is electrically coupled to a right chamber, The signal generator generates pacing pulses. The lead couples the signal generator to the first electrode and includes a distal end to be coupled to the second electrode. The lead further includes a delay element between the first electrode and the second electrode. The delay element prevents the second electrode from receiving a pacing pulse until after a predetermined delay period.

In accordance with another aspect of the present invention, a bi-chamber cardiac pacemaker comprises a first electrode, a second electrode, a signal generator, a first lead, a second lead, and a distributor circuit. The first electrode is electrically coupled to a left chamber. The second electrode is electrically coupled to a right chamber. The signal generator generates a sequential pair of electrical pacing pulses. The first lead couples the signal generator and the first electrode. The second lead couples the signal generator and the second electrode. The distributor circuit is connected between the first lead and the signal generator and between the second lead and the signal generator. The distributor circuit receives the pair of electrical pacing pulses, distributes a first pacing pulse of the pair at a first amplitude to the first lead, and distributes a second pacing pulse of the pair at a second amplitude to the second lead after a delay period.

In accordance with yet another aspect of the present invention, a bi-chamber cardiac pacemaker comprises a first electrode, a second electrode, a signal generator, a first lead, a second lead, and a distributor circuit. The first electrode electrically is coupled to a left chamber and the second electrode is electrically coupled to a right chamber. The signal generator generates an electrical pulse. The first lead couples the signal generator and the first electrode. The second lead couples the signal generator and the second electrode. The distributor circuit is connected between the first lead and the signal generator and between the second lead and the signal generator. The distributor circuit distributes pacing pulses to the first lead at a first amplitude and to the second lead at a second amplitude in response to the electrical pulse generated by the signal generator.

Additional features and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The features and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

## BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and together with the description, serve to explain the principles of the invention. In the figures:

FIG. **1** illustrates an environment in which methods, apparatus, and systems may be applied consistent with the principles of the present invention;

FIG. **2** illustrates a functional block diagram of a controller with multiple leads for controlling contraction of a heart consistent with the principles of the present invention;

FIG. **3** illustrates an example of a controller with multiple leads having internal delay elements consistent with the principles of the present invention;

FIG. **4** illustrates a block diagram of an embodiment of a controller that includes multiple leads with respective clamping circuits consistent with the principles of the present invention;

FIG. **5** illustrates a functional block diagram of a controller having a single lead with multiple wires consistent with the principles of the present invention;

FIG. **6** illustrates an example of a distributor consistent with the principles of the present invention;

FIG. **7** illustrates another example of a distributor consistent with the principles of the present invention;

FIG. **8** illustrates another example of a distributor consistent with the principles of the present invention; and

FIG. **9** illustrates a block diagram of a signal generator that includes a clamping circuit consistent with the principles of the present invention.

## DESCRIPTION OF THE EMBODIMENTS

Methods, apparatus, and systems are provided to control contraction of the heart. In particular, a controller is provided with a distributor that is configured to distribute stimulating signals to multiple sites in a heart via one or more leads. In addition, the controller may vary the timing of the stimulating signals such that stimulation of the multiple sites in the heart occurs with a delay. Methods, apparatus, and systems consistent with the present invention may provide dual chamber pacing (for example, DDD or DDI), bi-chamber pacing (i.e., bi-ventricular or bi-atrial), multiple stimulation to a single chamber, or any desired combination of these pacing modalities.

Reference will now be made in detail to exemplary embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

FIG. **1** illustrates an environment in which methods, apparatus, and systems may be applied consistent with the principles of the present invention. As shown, a controller **104** may accompany a heart **102**. In addition, heart **102** is shown with a superior vena cava **106**, a right atrium **108**, a left atrium **110**, a right ventricle **112**, a left ventricle **114**, a sinoatrial node ("SA node") **116**, an atrial-ventricular node ("AV node") **118**, a Bundle of His **120**, a right bundle branch **122**, a left bundle branch **124**, and Purkinje fibers **126**.

Heart **102** normally contracts in two stages based on sinus rhythm. Sinus rhythm is where heart **102** contracts in response to electrical impulses generated from SA node **116**. In order to cause contraction in the cardiac muscle of heart **102**, the electrical impulses from SA node **116** must depolarize the muscle fibers above a threshold voltage of approximately −80 mV.

In particular, as electrical impulses propagate from SA node **116** to AV node **118**, right atrium **108** and left atrium **110** contract. AV node **118** may then provide an AV delay of approximately **120** to **200** milliseconds that allows right ventricle **112** and left ventricle **114** to fill with blood.

After the AV delay, AV node **118** then emits another electrical impulse. This electrical impulse propagates relatively quickly over heart **102** down Bundle of His **120**, and over right bundle branch **122**, left bundle branch **124**, and Purkinje fibers **126**. In response, cardiac muscles in right ventricle **112** and left ventricle **114** depolarize and contract to pump blood to the rest of the body (not shown).

Controller **104** assists heart **102** to contract in a coordinated fashion based, for example, on sinus rhythm. Controller **104** may assist heart **102** by applying one or more electrical pulses to one or more sites in heart **102** and cause contraction in the chambers of heart **102**, such as right ventricle **112** and left ventricle **114**. Controller **104** may vary the timing that the stimulating electrical pulses are applied to heart **102**. In addition, controller **104** may be configured to selectively apply the stimulating electrical pulses to one or more of the sites in heart **102**.

As shown in FIG. **1**, controller **104** may be coupled to heart **102** using leads **128** and **129**. Leads **128** and **129** may be installed endocardially into heart **102** via superior vena cava **106** using known surgical procedures. Leads **128** and **129** may be implemented as a hollow catheter made of an insulating material, such as silicone rubber, and include one or more connection paths made of a conductive material, such as a wire made of stainless steel or other metal. The one or more connection paths of leads **128** and **129** may carry signals back and forth between heart **102** and controller **104**. For example, the one or more connection paths of leads **128** and **129** may carry signals that represent the electrical activity of heart **102** from heart **102** to controller **104**. In addition, the one or more connection paths of leads **128** and **129** may carry electrical signals, such as stimulating electrical pulses, from controller **104** to heart **102**.

For example, in one embodiment, lead **128** may be structured to include an atrial lead branch **130**, an atrial electrode **132**, a right ventricle lead branch **134**, and a right ventricle electrode **136**. Lead **129** may be structured to include a left ventricle lead branch **138** and a left ventricle electrode **140**. Although FIG. **1** illustrates two leads (i.e., leads **128** and **129**), any number of leads may be used to couple controller **104** to heart **102**. In addition, each lead may include any number of connection paths, e.g., wires.

Atrial lead branch **130** of lead **128** provides a connection path between controller **104** and right atrium **108** for carrying signals associated with right atrium **108** and SA node **116** from heart **102** to controller **104** and for carrying stimulating electrical signals from controller **104** to heart **102**. Although atrial lead branch **130** is shown as a branch of lead **128**, atrial lead branch **130** may be implemented using a separate lead from controller **104**.

Atrial electrode **132** is provided at the tip of atrial lead branch **130** and physically contacts one or more sites in right atrium **108**. Atrial electrode **132** senses the electrical activity in heart **102** associated with right atrium **108** and SA node **116**. In addition, atrial electrode **132** delivers the stimulating electrical signals from controller **104** to right atrium **108**. Atrial electrode **132** may be implemented, for example, as a helical coil of wire made of a metal, such as stainless steel. Atrial electrode **132** may be implemented using other known structures and may also comprise a plurality of electrodes.

Right ventricle lead branch **134** of lead **128** provides a connection path for carrying signals associated with right ventricle **1 12** from heart **102** to controller **104** and for carrying stimulating electrical signals from controller **104** to right ventricle **112**. Although right ventricle lead branch **134** is shown as a branch of lead **128**, right ventricle lead branch **134** may be implemented using a separate lead from controller **104**.

Right ventricle electrode **136** is provided at the tip of right ventricle lead branch **132** and physically contacts one or more sites in right ventricle **112**. Right ventricle electrode **136** senses the electrical activity in heart **102** associated with right ventricle **112**, such as electrical impulses from AV node **1 18** that are propagating over right bundle branch **122**. In addition, right ventricle electrode **136** delivers the stimulating electrical signals from controller **104** to right ventricle **112**. Right ventricle electrode **136** may be implemented, for example, as a helical coil of wire made of a metal, such as stainless steel. Right ventricle electrode **136** may be implemented using other known structures and may also comprise a plurality of electrodes.

Left ventricle lead branch **138** of lead **129** provides a connection path for carrying signals associated with left ventricle **114** from heart **102** to controller **104** and for carrying electrical signals from controller **104** to left ventricle **114**. Although left ventricle lead branch **138** is shown as a branch of lead **129**, left ventricle lead branch **138** may also be implemented using a separate lead from controller **104**.

Left ventricle electrode **140** is provided at the tip of left ventricle lead branch **138** and physically contacts one or more sites in left ventricle **114**. Left ventricle electrode **140** senses electrical activity in heart **102** associated with left ventricle **114**, such as electrical impulses from AV node **118** that are propagating over left bundle branch **124**. Left ventricle electrode **140** may be implemented, for example, as a helical coil of wire made of a metal, such as stainless steel. Left ventricle electrode **140** may be implemented using other known structures and may also comprise a plurality of electrodes.

The lead configuration illustrated in FIG. **1** is but one example for providing bi-chamber stimulation. One of ordinary skill will appreciate that methods, systems, and apparatus consistent with the present invention may use any lead configuration that allows for stimulation of any combination of chambers or sites in heart **102**. By way of example only, the leads of controller **104** could provide for sensing and/or pacing in (1) right ventricle **112** and right atrium **108**, (2) left ventricle **114** and left atrium **110**, (3) right ventricle **112** and left ventricle **114**, (4) the right and left atria **108** and **110**, respectively, (5) two sites in a single chamber, such as left ventricle **114**, or any combination of the above.

FIG. **2** illustrates a functional block diagram of controller **104** with multiple leads for controlling contraction of heart **102** consistent with the principles of the present invention. As shown, controller **104** includes sense amplifiers **200**, **202**, and **204**, a processor **206**, a memory **208**, a telemetry module **210**, a signal generator **212**, and a distributor **214**.

Sense amplifiers **200**, **202**, and **204** are coupled via lead **128** to atrial electrode **132**, right ventricle electrode **136**, and left ventricle electrode **140**, respectively. Sense amplifiers **200**, **202**, and **204** receive signals indicating electrical activity of heart **102** from their respective electrodes, amplify these signals, and provide them to processor **206**. Sense amplifiers **200**, **202**, and **204** may be implemented using, for example, well known circuitry.

Processor **206** receives and monitors signals from sense amplifiers **200**, **202**, and **204** and generates one or more control signals. For example, processor **206** may detect the sinus rhythm of heart **102** based on signals received from atrial electrode **132**. Processor **308** may then monitor the electrical activity of right ventricle **112** and left ventricle **114** based on signals received from right ventricle electrode **136** and left ventricle electrode **140**. If the electrical activity in right ventricle **112** fails to reach a threshold level within a period of time corresponding, for example, to a desired A-V delay period, then processor **206** may be configured to provide one or more control signals to signal generator **212**. The one or more control signals then command signal generator **212** to deliver one or more stimulating electrical pacing pulses to chambers of heart **102**, such as right ventricle **112** and/or left ventricle **114**.

Alternatively, processor **206** may be configured to provide the one or more control signals to signal generator **212** automatically. For example, upon detecting the sinus rhythm of heart **102** based on signals received from atrial electrode **132**, processor **206** may be configured to automatically provide the one or more control signals that commands signal generator **212** to stimulate one or more chambers of heart **102**, such as right ventricle **112** and left ventricle **114**, automatically.

Processor **206** may be implemented using known devices. For example, processor **206** may be implemented using a series of digital circuits or logic gates. Alternatively, processor **206** may be implemented using a microprocessor, such as those manufactured by the Intel Corporation.

Memory **208** provides storage for information used by processor **206**. For example, memory **208** may include instructions for configuring processor **206** and instructions for monitoring the electrical activity of heart **102**. Memory **208** may be implemented using known types of memory, such as a random access memory and read-only memory.

Telemetry module **210** provides diagnostic information indicating the performance of controller **104**. For example, telemetry module **210** may transmit the signals received from sense amplifiers **200**, **202**, and **204**, and signals generated by signal generator **212** via a radio link to another device, such as an external programmer (not shown). Telemetry module **210** may also collect and transmit other types of information. Telemetry module **210** may be implemented as a radio receiver/transmitter using a known radio frequency, such as 100 kHz.

Signal generator **212** generates electrical pulses for treating heart **102**, for example, via lead **128**. The electrical pulses from signal generator **212** may be delivered to, for example, right ventricle **112** and left ventricle **114** respectively via right ventricle lead branch **134** and left ventricle lead branch **138** of lead **128**. In particular, signal generator **212** may provide, for example, a cathodal pulse of 5 V for a duration of approximately 2 milliseconds to stimulate contraction in heart **102**.

When treating heart **102**, signal generator **212** may vary the electrical pacing pulses delivered to heart **102**. Signal generator **212** may vary the number of pulses, the pulse amplitude, and pulse width. For example, signal generator **212** may generate electrical pacing pulses in sequential pairs to stimulate contraction in one or more chambers of heart **102**, such as right atrium **108** and right ventricle **112**. Alternatively, signal generator **212** may manipulate the pulse amplitude and duration of its pulses in response to conditions measured from heart **102**. Signal generator **212** may also use other types of pulses, such as biphasic pulses or anodal pulses, to stimulate contraction in heart **102**.

in one embodiment, signal generator **212** is implemented using known circuitry, such as "one-shot" circuitry, that is triggered by processor **206**. Alternatively, signal generator **212** may be implemented using other known components, such as a capacitor coupled to a continuous charger.

Distributor **214** receives the electrical pacing pulses from signal generator **212** and, in response, distributes the one or more electrical pacing pulses to one or more chambers of heart **102**, such as right ventricle **112**, left ventricle **114**, etc., based on one or more control signals from processor **206**. When distributing pulses, distributor **214** may vary the delay time between pulses, or inhibit one or more of the pulses based on the control signals from processor **206**. One skilled in the art would also recognize that distributor **214** may vary other characteristics of the pulses, such as the amplitude, based on the control signals from processor **206**.

Distributor **214** may be configured in various ways to manipulate the distribution of the electrical pulses to heart **102**. For example, distributor **214** may be implemented using a variety of circuits and digital logic, such as flip-flops, multiplexers, Schmidt triggers, etc. Various examples of distributor **214** are described in more detail with reference to FIGS. **6**-**8**.

FIG. **3** illustrates a block diagram of one embodiment of controller **104** having multiple leads that include internal delay elements consistent with the principles of the present invention. In particular, delay elements **300** and **302** are shown within leads **128** and **129** respectively. Upon receiving electrical pacing pulses, delay elements **300** and **302** may delay the delivery of these pulses between right ventricle **112** and left ventricle **114**, or between right atrium **108** and right ventricle **112**, etc. In one embodiment, delay elements **300** and **302** are implemented as inductive elements to delay the delivery of pulses. One skilled in the art would also recognize that other types of components may be used within delay **300** and **302** to delay the delivery of pulses.

FIG. **4** illustrates a block diagram of an embodiment of controller **104** that includes multiple leads with respective clamping circuits consistent with the principles of the present invention. As shown, controller **104** may include clamping circuits **400***a* and **400***b* at the output of distributor **214**. Clamping circuits **400***a*-*b* allow controller **104** to selectively suppress or clamp the one or more electrical pacing pulses as they are output from distributor **214** and thereby vary the amplitude of a pulse or altogether inhibit application of a pulse. Use of clamping circuits **400***a*-*b* may be useful when, for example, controller **104** has detected spontaneous depolarization in a chamber of heart **102**.

In particular, controller **104** may suppress or clamp the electrical pacing pulses when processor **206** detects spontaneous depolarization in heart **102** and determines that heart **102** does not require assistance based on signals received from electrodes **132**, **136**, and **140**. The signals from electrodes **132**, **136**, and **140** may also indicate that the electrical impulses of sinus rhythm in heart **102** are propagating normally. Accordingly, processor **206** may send one or more control signals to clamping circuits **400***a* and/or **400***b*. In response, camping circuits **400***a*-*b* may then alter or suppress electrical pacing pulses output from distributor **214**. Although clamping circuits **400***a*-*b* are shown connected at the output of distributor **214**, clamping circuits **400***a*-*b* may be installed anywhere in controller **104**, such as between signal generator **212** and distributor **214**. Clamping circuits **400***a*-*b* are also described in more detail with reference to FIG. **9**

FIG. **5** shows a block diagram of one embodiment of controller **104** having a single lead with multiple wires consistent with the principles of the present invention. In particular, controller **104** is coupled to heart **102** via a single lead, i.e., lead **128** instead of multiple leads as shown in FIGS. **1**-**4**. In this embodiment, lead **128** further includes multiple wires, such as wires **500** and **502**. Wires **500** and **502** provide respective connection paths to sites within heart **102**, such as sites within right atrium **108**, right ventricle **112** and/or left ventricle **114**. Although FIG. **5** illustrates two wires within lead **128**, i.e., wires **500** and **502**, lead **128** may include any number of wires. Wires **500** and **502** may be constructed from known conductive materials, such as stainless steel, copper, or other metal. One skilled in the art would also recognize when controller **104** should be implemented with one lead having multiple wires or with multiple leads.

FIG. **6** illustrates an example of distributor **214** consistent with the principles of the present invention. As shown in FIG. **6**, distributor **214** may be implemented as a bistable flip-flop that is triggered by one or more signals from signal generator **212**. In particular, one or more signals from signal generator **212** are received at inputs **600** and **602**. Capacitors **604** and **606** are coupled to inputs **600** and **602** respectively and charge and discharge in response to the one or more signals. The charge/discharge of capacitors **604** and **606** cause transistors **608** and **610** to turn on and then off. The cycling of transistors **608** and **610** subsequently generate electrical pacing pulses at outputs **612** and **614**. Outputs **612** and **614** are then coupled to lead **128** and/or lead **129** to provide the electrical pacing pulses to one or more chambers of heart **102**. Alternatively, when controller **104** is implemented with a single lead as shown in FIG. **5**, outputs **612** and **614** may be coupled to wires **500** and **502** to provide the electrical pacing pulses to heart **102**.

The characteristics of the electrical pacing pulses, such as their amplitude and pulse width, are determined based on the values of resistors **616**, **618**, **620**, **622**, and **624** and capacitors **626** and **628**. The values of these components may be predetermined. Alternatively, distributor **214** may manipulate or set one or more of these values in response to control signals from processor **206**. Resistors **616**, **618**, **620**, **622**, and **624** and capacitors **626** and **628** are implemented using known components. Moreover, distributor **214** may manipulate the above components to control the delay between pulses.

FIG. **7** illustrates another example of distributor **214** consistent with the principles of the present invention. As shown, distributor **214** may be implemented as an array of "LC" circuits comprising inductors **702**, **704**, and **706**, and capacitors **708**, **710**, and **712**. In particular, the signal from signal generator **212** may be used energize the LC circuits of distributor **214**. In one embodiment, inductors **702**, **704**, and **706** may be set to a particular inductive value for a desired delay between electrical pacing pulses based on a control signal from processor **206**. Processor **206** may determine the values for inductors **702**, **704**, and **706** based on information received via telemetry module **210**.

In order to trigger application of the electrical pacing pulses, distributor **214** may include diodes **716** and **718**, which are biased based on the voltage output of the LC circuits. For example, in one embodiment, diodes **716** and **718** may be implemented as Zener diodes that discharge when the respective LC circuits for diodes **716** and **718** reach a threshold voltage. Alternatively, diodes **716** and **718** may provide electrical pacing pulses based on a local electrical state of electrodes, such as electrodes **132**, **136**, and **140**, within heart **102**. In particular, diodes **716** and **718** may be implemented as silicon controlled rectifiers, which are gated based on control signals from processor **206**. Processor **206** may generate the control signals in response to signals received from sense amplifiers **200**, **202**, and **204**, which are coupled to electrodes **132**, **136**, and **140** respectively.

Upon reaching the threshold voltage, diodes **716** and **718** then discharge electrical pacing pulses to outputs **720** and **722**. Outputs **720** and **722** are then coupled to lead **128** and/or lead **129** to provide the one or more electrical pacing pulses to one or more chambers of heart **102**. Alternatively, when controller **104** is implemented with a single lead as shown in FIG. **5**, outputs **720** and **722** may be coupled to wires **500** and **502** to provide the electrical pacing pulses to heart **102**. One skilled in the art would also recognize that distributor **214** may vary the amplitude of the electrical pulses using, for example, known circuitry (not shown) or provide the electrical pulses at a single amplitude, for example, by implementing diodes **716** and **718** as Zener diodes.

FIG. **8** illustrates another exemplary distributor **214** consistent with the principles of the present invention. As shown, distributor **214** may include a switching element **800** that routes the one or more electrical pulses from signal generator **212** to leads **128** and **129**. In addition, distributor **214** may also include shunt resistors **802** and **804** to set the amplitude of pulses delivered to leads **128** and **129** respectively. The value of resistors **802** and **804** may, for example, be set in response to control signals from processor **206**. Resistors **802** and **804** may be implemented using known components.

Switching element **800** may be implemented using known components, such as transistors or thyristors. Alternatively, switching element **800** may include a unistable electronic switch, which is followed by a bistable flip-flop to distribute electrical pacing pulses to leads **128** and **129**. When controller **104** is implemented with a single lead as shown in FIG. **5**, one skilled in the art would also recognize that the output of switch **800** may be coupled to wires **500** and **502** to provide electrical pacing pulses to heart **102**.

Switching element **800** may distribute electrical pacing pulses based on a delay, for example, in response to control signals from processor **206**. The delay may be a predetermined amount or specified by the one or more control signals from processor **206**. In this embodiment, distributor **214** may also include other circuitry, such as a one-shot circuit (not shown) and threshold comparators, for example, to vary the delay between the pulses delivered to the right ventricle electrode **136** and left ventricle electrode **140**.

FIG. **9** illustrates an example of clamping circuits **400***a*-*b* consistent with the principles of the present invention. As described below, clamping circuit **400***a* (or **400***b*) clamps or suppresses a signal, such as the output of distributor **214**, in response to a control signal (i.e., a clamping signal) from processor **206**. As shown, in one embodiment, clamping circuit **400***a* may include components, such as operational amplifiers **902**, **904**, **906**, **908**, and **910**, and diodes **912** and **914**.

Clamping circuit **400***a* receives an input signal **916** from distributor **214** and a clamping signal **918** from processor **206**. Input signal **916** is fed to operational amplifier **904**, which is configured as a unity-gain buffer. The output of operational amplifier **904** is then fed to an input of operational amplifier **910** and the outputs of operational amplifiers **906** and **908** via diodes **914** and **912** respectively. The output of operational amplifier **904** is also fed back to inputs of operational amplifiers **906** and **908**.

Clamping signal **918** is fed to operational amplifier **902**, which is also configured as a unity-gain buffer. The output of operation amplifier **902** is then provided to inputs of operational amplifiers **906** and **908**. Operational amplifiers **906** and **908** operate in conjunction with diodes **914** and **912** to clamp or suppress input signal **916** based on the relative values for input signal **916** and clamping signal **918**.

For example, when input signal **916** is less than clamping signal **918**, operational amplifiers **906** and **908** and diodes **914** and **912** are biased such that pacing signal **920** will be substantially the same value as input signal **916**. Clamping circuit **900** then outputs pacing signal **920** from operational amplifier **910** to lead **128** and/or lead **129**. However, when input signal **916** exceeds clamping signal **918**, operational amplifiers **906** and **908** and diodes **914** and **912** are biased such that pacing signal **920** will be the same value as clamping signal **920**.

Accordingly, if clamping or suppression of electrical pacing pulses is desired, controller **104** may use processor **206** to send one or more control signals, such as clamping signal **918**, to clamping circuit **400***a* (or **400***b*). For example, if processor **206** decides to suppress one or more electrical pacing pulses from signal generator **212**, processor **206** may set clamping signal **918** to an appropriate value, such as 0 volts. In addition, if processor **206** detects that heart **102** requires assistance, then processor **206** may set clamping signal **918** to an appropriate value, such as 5-10 volts, such that electrical pacing pulses pass through clamping circuit **400***a*.

Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. For example, while one embodiment describes a three-chamber cardiac stimulation device, one of ordinary skill would appreciate that the present invention could be used in a four-chamber device, a two-chamber device, or even a single-chamber device having multiple intrachamber stimulation sites. Likewise, although FIGS. **2-4** illustrate sense amplifiers **200**, **202**, and **204**, systems, methods and apparatus consistent with the present invention may use any desired number of sense amplifiers **200**, **202**, and **204**. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims.

What is claimed is:

1. A bi-chamber cardiac pacemaker, comprising:

a first electrode electrically coupled to a left ventricle;

a second electrode electrically coupled to a right ventricle;

a single signal generator to generate pacing pulses based on electrical activity in the left and right ventricles relative to a predetermined atrio-ventricular delay period; and

a lead to connect the single signal generator to the first electrode and to the second electrode, the second electrode being coupled to a distal end of the lead, the lead further including a delay element between the first electrode and the second electrode to prevent the second electrode from receiving a pacing pulse until after a specified delay period relative to receipt of the pacing pulse at the first electrode.

2. The bi-chamber cardiac pacemaker of claim 1, wherein the delay element comprises an inductor.

3. The bi-chamber cardiac pacemaker of claim 1, wherein the delay element comprises a capacitor.

4. A bi-chamber cardiac pacemaker, comprising:

a first electrode electrically coupled to a left ventricle;

a second electrode electrically coupled to a right ventricle;

a single signal generator to generate a sequential pair of electrical pacing pulses based electrical activity in the left and right ventricles relative to a predetermined atrio-ventricular delay period;

a first lead coupled to the single signal generator and to the first electrode;

a second lead coupled to the single signal generator and to the second electrode; and

a distributor circuit, connected between the first lead and the single signal generator and between the second lead and the single signal generator, to receive the pair of electrical pacing pulses, distribute a first pacing pulse of the pair at a first amplitude to the first lead, and distribute a second pacing pulse of the pair at a second, different amplitude to the second lead after a delay period relative to receipt of the first pacing pulse at the first electrode.

5. The bi-chamber cardiac pacemaker according to claim 4, wherein the distributor circuit includes,

a first transistor connected between the single signal generator and the first lead to distribute pacing pulses to the first lead;

a second transistor connected between the single signal generator and the second lead to distribute pacing pulses to the second lead;

a first passive network connected between a gate of the first transistor and a collector of the second transistor; and

a second passive network connected between a gate of the second transistor and a collector of the first transistor,

wherein the first and second passive networks bias the first and second transistors to alternate pulse distribution between the first and second leads.

6. A bi-chamber cardiac pacemaker, comprising:

a first electrode electrically coupled to a left ventricle;

a second electrode electrically coupled to a right ventricle;

a single signal generator to generate at least one electrical pulse based on electrical activity in the left and right ventricles relative to a predetermined atrio-ventricular delay period;

a first lead coupled to the single signal generator and to the first electrode;

a second lead coupled to the single signal generator and to the second electrode; and

a distributor circuit, connected between the first lead and the single signal generator and between the second lead and the single signal generator, to distribute pacing pulses to the first lead at a first amplitude and to the second lead at a second, different amplitude in response to the at least one electrical pulse generated by the signal generator.

7. The bi-chamber cardiac pacemaker of claim 6, further comprising:

a delay circuit, connected between the single signal generator and the first lead and between the single signal generator and the second lead, to prevent the second electrode from receiving the second pacing pulse until after a specified delay period.

8. The bi-chamber cardiac pacemaker of claim 6, the second lead further comprising a delay element to prevent the second electrode from receiving the second pacing pulse until after a specified delay period.

9. A bi-chamber cardiac pacemaker apparatus, comprising:

first means for electrically coupling the apparatus to a left ventricle;

second means for electrically coupling the apparatus to a right ventricle;

single means for generating pacing pulses based on electrical activity in the left and right ventricles relative to a predetermined atrio-ventricular delay period; and

means for electrically coupling the single means for generating to the first and second means and for delaying at least one of the pacing pulses for a predetermined delay period.

10. A bi-chamber cardiac pacemaker apparatus, comprising:

first means for electrically coupling the apparatus to a left ventricle;

second means for electrically coupling the apparatus to a right ventricle;

single means for generating a sequential pair of electrical pacing pulses based on electrical activity in the left and right ventricles relative to a predetermined atrio-ventricular delay period; and

means for receiving the pair of electrical pacing pulses from the single means for generating, for distributing a first pacing pulse of the pair at a first amplitude from the means for generating to the first means, and for distributing a second pacing pulse of the pair at a second, different amplitude from the single means for generating to the second means after a delay period.

11. A bi-chamber cardiac pacemaker apparatus, comprising:

first means for electrically coupling the apparatus to a left ventricle;

second means for electrically coupling the apparatus to a right ventricle;

single means for generating at least one electrical pulse based on electrical activity in the left and right ventricles relative to a predetermined atrio-ventricular delay period; and

means for distributing the electrical pacing pulses from the single means for generating to the first means at a first amplitude and to the second means at a second, different amplitude in response to the at least one electrical pulse generated by the single means for generating.

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